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China's energy situation in the new millennium

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ABSTRACT

Many are interested in China's energy situation, however, many energy related issues in China still remain unanswered, for example, what are the potential forces driving energy demand and supply? Previous reviews focused only on fossil fuel based energy and ignored other important elements including renewable and 'clean' energy sources. The work presented here is intended to fill this gap by bringing the research on fossil-based and renewable energy economic studies together and identifying the potential drivers behind both energy demand and supply to provide a complete picture of China's energy situation in the new millennium. This will be of interest to anyone concerned with the development of China's economy in general and the energy economy, in particular.

Contents

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Understanding China's energy economy in the new millennium is crucial for politicians, business people and energy economists. In particular, China's energy policy directions will present both challenges and opportunities to the world in terms of an increasing share of primary energy consumption and investment opportunities [1,2]. China's industrialization, modernization and urbanization affect the way in which energy resources will be developed as the basis of economic growth [3].

Many authors have focused on the energy situation in China [2–7], however, many energy related issues in China still remain unanswered, for example, what are the potential forces driving energy demand; what are the potential forces driving energy supply? Previous reviews focused only on fossil fuel based energy and ignored other important elements including renewable and 'clean' energy sources. Therefore, a comprehensive and complete review of the energy situation in China is timely and necessary. The work presented here is intended to fill this gap by bringing the research on fossil-based and renewable energy economic studies together and identifying the potential drivers behind both energy demand and supply to provide a complete picture of China's energy situation in the new millennium. This will be of interest to anyone concerned with the development of China's economy in general and the energy economy, in particular.

The review of China's energy situation is organized as follows. Firstly, we consider the historical origins of China's current energy situation. This is followed by an investigation and analysis of China's energy resources, including renewable energy. In the third section we consider the energy industrial regulations. Section 4 focuses on capacity building in the energy sector. Sections 5 and 6 describe energy transportation (focusing on coal) and energy price information. Section 7 discusses China's energy efficiency in particular, energy intensity over time and across regions. This is followed by a discussion of energy supply, demand and trade. Section 9 reviews China's renewable energy law, programs and policy. Section 10 discusses the potential factors driving demand and supply followed by policy directions in energy economic development. The final section presents some conclusions.

1. An historical perspective of China's energy situation

As early as 1974, Dean considered the energy situation in the People's Republic of China and argued that the discovery and initial exploration of new petroleum reserves were significant changes to energy policy and operation. In particular, he was concerned with future developments in the energy industry and the effect on the international energy market. He argued that the size of China's fossil fuel and hydroelectric resources, combining with the commitment to 'self-reliance' made it unlikely that China would become a major energy importer. Furthermore, he argued that China would likely become a major exporter in the foreseeable future. By 1992 China had, in fact, become a major energy importer.

Dorian and Clark [4] discussed potential supply problems and implications for China's energy resources. They stated that primary energy production must increase significantly by the year 2000 if China was to achieve its current modernization and economic objectives. To support and sustain this rapid economic growth, indigenous supplies of primary energy resources would have to be developed at rates greater than those of the time. With a specific concern for China's sustainable energy supplies, they conducted a

systematic assessment of China's primary energy resources by Province using the Unit Regional Production Value (URPV) technique, originally developed by Griffiths [8]. What is interesting is that they present the potential for petroleum, natural gas, coal and uranium by Province. The detailed URPV of petroleum, natural gas and coal see Figs. 2–4 of Dorian and Clark [4]. Once they had identified the potential supply of petroleum, natural gas and coal by Province they consider the extent to which exploration is restricted by outdated equipment and poor management. Furthermore, they consider whether increased energy production may be limited by inadequate infrastructure combined with high capital requirements, safety and environmental issues.

Kambara [5] investigated China's energy situation in the 1980s. He considered economic growth and energy consumption and, in turn, the energy intensity by sector and by region, observing the changing patterns of energy supply and demand. He then, raised a number of issues, including the unequal distribution of energy reserves, rising investment cost, limited funds and lack of technology imports which he believed have constrained China's energy supplies. He stated that his review of China's energy situation suggests that supplies of, and demand for, energy will grow in a 'balanced fashion' that will keep pace with economic development. Finally, he argued that the most important task facing China was to totally reform the energy market, particularly pricing to eliminate wasted generation caused by low energy prices. The current 'partially liberalized' market, he argued, actually caused more confusion than benefits.

Wu and Li [6] studied developments in China's energy situation in the 1980s and early 1990s. They described commercial energy production and consumption and stated that certain features of China's energy production and consumption have had a profound impact on the country's energy development strategies and policies. Much of their work, therefore, focused on explaining these strategies and policies in China, fuel by fuel. Overall, they present two basic characteristics of China's energy industry associated with China's policies for energy development. The first is that China's energy policy has varied over the last several decades consistent with domestic and international situation. The second is that China does not have a unified national energy development strategy as energy resources are not all substitutes and the distribution of energy resources is uneven across regions or Provinces. As a result the 'national' energy policies have become de facto 'regional energy development policies' with each of the major energy industries developing their own strategies. In conclusion the authors recommend that China offer; more flexible terms to attract foreign investment in the energy sector; formulate a comprehensive oil import policy; improve the legislative and business climate to support fair competition; ensure balanced growth of coal production and transportation; limit the monopoly power of railway transportation through government intervention, and finally reform electricity pricing.

There is abundance of coal and the lack of natural gas in China, where coal extraction originates from two types of enterprises—large collieries owned by the state and administrated from Beijing and a variety of local medium and small mines run by counties, townships, collectives and even individuals [9]. It is a common phenomenon in China that growth in output has not been accompanied by improvements in quality. Attempts to open small mines, without geological and technical evaluation, has led to a significant waste of coal resources. Primitive extraction methods and inexperienced operators have led to a very low recovery rate and often extensive destruction of arable and grazing land. Rapid economic expansion and the continuing reliance on coal can be expected to more than double China's current carbon dioxide emissions are forecast to rise significantly with a large increase in the other greenhouse gases [7,10].

It is very surprising that the reviews summarized above have not been mentioned any renewable energy at all given that renewable energy has been playing an important role in China's energy supply. China's population is over 1.2 billion where more than 60% live in rural areas where most of households use renewable energy (e.g., biomass, biogas) rather than fossil fuel based energy [11,12]. For example, since 2000 renewable energy has accounted for approximately 74% of China's total rural residential energy consumption [13]. Meanwhile, China's urbanization is gradually reshaping the pattern of rural energy consumption away from biomass energy-based to cleaner energy sources [14]. This will undoubtedly lead to more pressure on nonrenewable energy demand.

The energy situation in China is highly dynamic. Do the concerns raised above persist? Did China follow the policies suggested above? What does the current energy situation in China look like? Are there any new concerns that have appeared? Are there any new policies that have been proposed? The following section presents an overview of the current energy situation in China.

2. China's energy resources

The issue of China's energy reserves is of long standing interest to researchers and policy makers. Issues related to general energy reserves can be found in BP [15] and energy potential in Dorian and Clark [4]. Here we present three figures to illustrate China's energy reserves and their distribution over Provinces as it helps understand issues related to energy transportation and policies on energy exploration and regional development.

2.1. Coal reserves

China's proven reserves of anthracite and bituminous coal are 62,200 million metric tonnes (mmt) and for sub-bituminous and lignite coal, 52,300 mmt [15]. The total proven coal reserves are therefore 114,500 mmt and account for 13.5% of total world stocks. As of the end of 2007, the ratio of reserves to production is 118 years. It is also widely known that China's distribution of coal is extremely uneven across regions. Fig. 1 shows the distribution of China's coal reserves by Province in 2004. Coal is found almost everywhere in China, but the major deposits are found in the North (Shanxi and Inner Mongolia), Southwest (Guizhou and Yunnan)

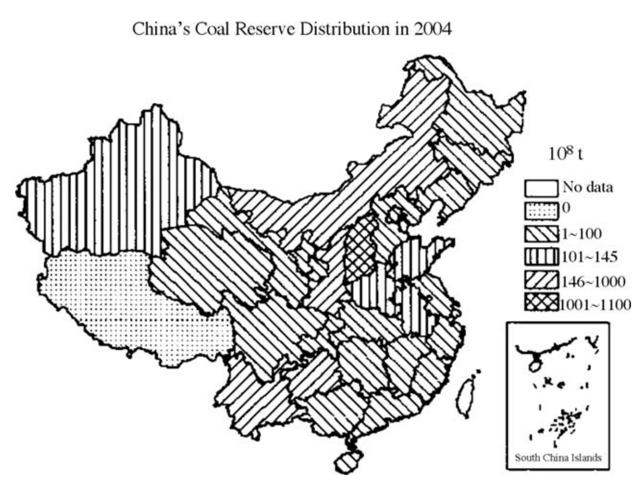

Fig. 1. China's coal reserve distribution in 2004. *Data source*: China Statistical Yearbook (2005) [17]. *Note*: According to BP [15], China's proved reserve of anthracite and bituminous coal is 62,200 million tonnes, and proved reserve of sub-bituminous and lignite coal is 52,300 million ones. The total proved coal reserve is 114,500 million tonnes and accounts for 13.5% of world total. The ratio of reserves to production is 118 at the end of 2007.

and Northwest (Shaanxi). Most coal reserves are located in Shanxi Province (over 100 billion metric tonnes).

2.2. Petroleum reserves

Statistics show a clear decline in China's proven and recoverable petroleum reserves. In 1987 there were 2377 mmt declining to 2322 mmt by the end of 1997 and 2117 mmt by 2008. Chinese petroleum reserves presently account for 1.3% of the world total [15]. As of the end 2007, the ratio of reserves to production was 11.3 years. Finding new oil fields and creating a comprehensive oil import policy package is one of the most important tasks for China to undertake. Similarly, oil reserves are not evenly distributed over Provinces see (Fig. 2), which shows stocks in favor of Northeast (Heilongjiang), East (Jiangsu) and Northwest (Xinjiang).

2.3. Natural gas reserves

China's proven reserves of natural gas are 1.9 trillion cubic meters and account for 1.1% of the world total. As of the end 2007, the ratio of reserves to production is 27.2. Natural gas reserves are mainly located in Southwest (Sichuan and Chongqing), West (Shaanxi), North (Inner Mongolia) and Northwest (Xinjiang) (see Fig. 3). There are two types of natural gas reserves—those which are independent of oil fields and those associated with oil reserves. Natural gas development is sluggish due to the absence of production facilities, transportation pipelines and urban gas supply systems. Nevertheless, China's natural gas resources are estimated to be large and more will no doubt be confirmed and developed. The most promising fields are in the Ordos basin, the Caidam Basin, and the Yinggehai Basin off Hainan Island Kambara [5].

2.4. Renewable energy

There are various renewable energy sources including hydropower, biomass, solar energy, wind energy, geothermal energy and wave energy currently used in China. It is currently estimated that the economically potential exploitable renewable energy resources amount to approximately 7.2 billion tonnes coal equivalent, while the current exploited renewable energy resource is only 0.1 billion tonnes coal equivalent [16]. Here we will consider only hydropower and biomass renewable energy as they are currently two of the most important sources of renewable energy in China.

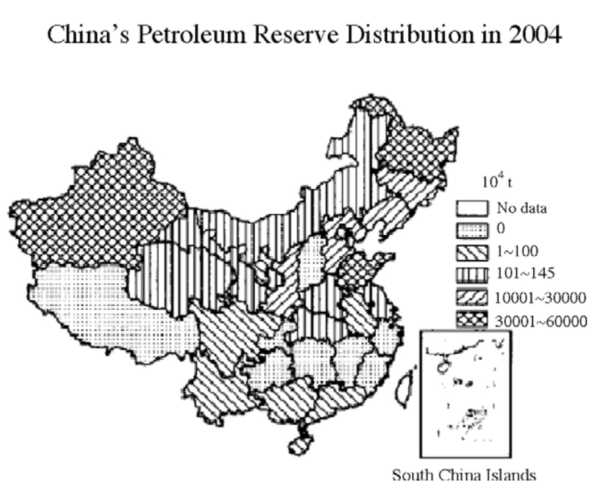

Fig. 2. China's petroleum reserve distribution in 2004. *Data source*: China Statistical Yearbook (2005) [17]. *Note*: China's proved reserve of oil is 2116.6 million tonnes and accounts for 1.3% of world total; the ratio of reserves to production is 11.3 at the end of 2007 [15].

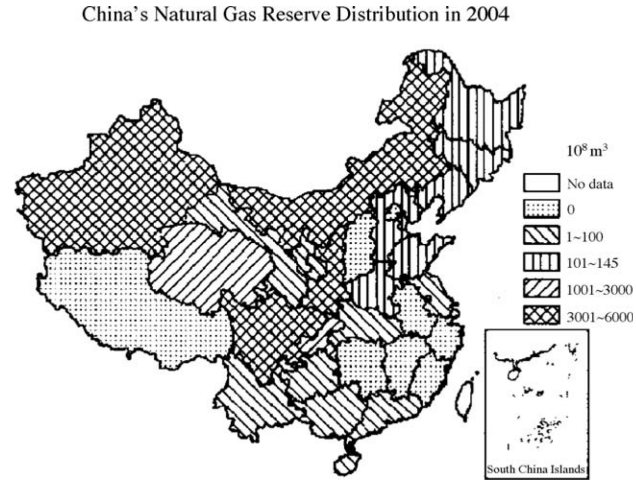

Fig. 3. China's natural gas reserve distribution in 2004. *Data source*: China Statistical Yearbook (2005) [17]. *Note*: China's proved reserve of natural gas is 1.9 trillion cubic meters and accounts for 1.1% of world total. The ratio of reserves to production is 27.2 at the end of 2007 [15].

2.4.1. Hydropower energy

China is rich in hydropower energy potential. Maximum exploitable hydropower resources are approximately 680 million kW,[2] of which 380–400 million kW is currently economic exploitable potential. To date, there has been total installed capacity of 116 million kW. China plans to install new capacity of 165 million kW by 2010 and 290 million kW by 2020.

Of 380–400 million kW of hydropower economic exploitable, there is 128 million kW from small hydropower stations (under 50,000 kW), located in 1600 countries across the country. Total installed capacity of small hydropower stations was 47 million kW in 2006. Total generation of rural hydropower was 148 billion kWh in 2006 [17]. China plans to install 50 million kW by 2010 and 75 million kW by 2020 for small hydropower station generation [16].

Small hydropower stations play an important role in China's rural electricity supply. Currently, approximately half of the territories, one third of counties and a quarter of the total population are dependent upon small-scale hydropower for rural electricity supply.

The distribution of small-scale hydropower generation, however, is uneven. Approximately 65% of small hydropower stations are located in the west and south of the country. In 2005, total installed capacity was approximately 24.7 million kW in the western areas of the country, which generated total hydroelectricity of 71.5 billion kWh.

2.4.2. Biomass energy

Potential for biomass energy in China includes crop stalks, firewood, foul waste, domestic garbage, industrial organic wastes and waste water, etc. It is estimated that total potential biomass energy is approximately 70–100 mmt coal equivalent, of which 50% comes from crop stalks, i.e., 35–50 mmt coal equivalent [18].

During the period 1995–2006, China produced approximately 620 million tonnes of crop stalks per year of which 50% comes from the east and central south of China. Crop residues amount to 1.3 times total crop output and 2 times that of the total fodder of

[2] This unit (kW) comes from China Energy Statistical Yearbook 2007 [13], which only indicates the installed capacity without providing much hydroelectricity generated annually.

grassland. Crop stalks of corn, wheat and rice amounted to 189, 136 and 237 million tonnes respectively accounting for over 85% of all crop stalks in 2006 [17]. At present, energy use accounts for approximately 37.5% of crop stalks, non-energy use accounts for approximately 27.5% of crop stalks with approximately 35.0% of crop stalks either lost during the harvest or discarded in the field [11]. This means that there is still 35% potential use of crop stalks as biomass energy in China's rural areas equivalent to over 50 mmt coal equivalent.

3. Energy industry regulation

3.1. Previous regulatory system

China's energy industry has experienced several significant policy and management changes. The 'old form' of energy industry regulation system was created in 1993. Fig. 4 shows the government structure and regulatory system as it was. The State Planning Commission (SPC, now called the State Development and Reform Commission—SDRC) reported to the State Council which stood at the top of the energy policy hierarchy with full responsibility for energy policy. The State Economic and Trade Commission (SETC, from which most functions have been transferred to the SDRC since 2001) and the State Sciences and Technology Commission (SSTC, now the Ministry of Sciences and Technology) played a relatively minor and subordinate role in the energy sector. Under this old system, each of the major energy industries was dominated by a single institution which was either a State Corporation or a Ministry. For example, the China National Petroleum Corporation (CNPC) dominated petroleum exploration and production, while the China Petroleum and Chemical Corporation (Sinopec) controlled oil refining and distribution. The Ministry of Electric Power (MEP) and Ministry of Coal Industries (MCI) were in charge of the power and coal sectors, respectively. These Corporations and Ministries were also involved in policy formulation, regulation and enterprise management [19].

The old industrial organization structure and regulatory system of China's energy sector have been well documented and reviewed, for example, energy policies prior to the 1970s were reviewed by Dean [3]. National policies and regional strategies of China's energy development were considered by Wu and Li [6]. The changes in China's power sector in the early 1990s were discussed by Li and Dorian [20]. China's energy and resource use during the first part of the 1990s were assessed by Smil [7]. China's reform of the coal industry during the 1980s and the early 1990s were reviewed by Thomson [21] and CIAB [2]. Decentralization of China's electricity sector in the 1980s was considered in Wirtshafter and Shih [22]. The reform of China's electric power industry and the foreign direct investment were discussed by Andrews-Speed and Dow [23] and Blackman and Wu [24], respectively.

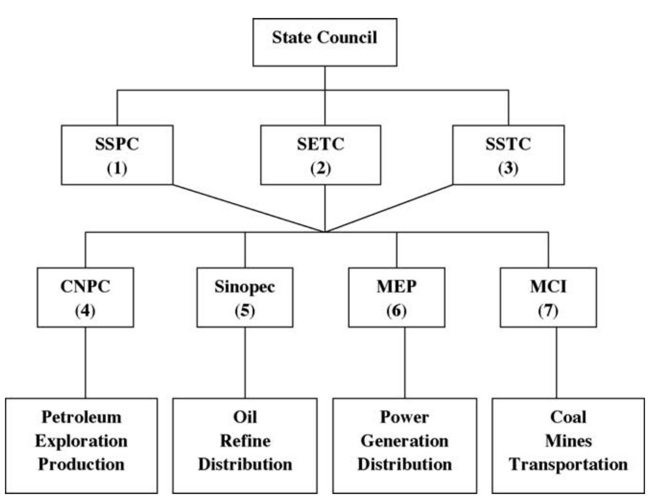

Fig. 4. Old government structure and regulatory system for energy sector setup in 1993. *Note*: (1) SSPC—State Planning Commission; (2) SETC—State Economic Trade Commission; (3) SSTC—State Science Technology Commission; (4) CNPC—China National Petroleum Corporation; (5) Sinopec—China Petroleum and Chemical Corporation; (6) MEP—Ministry of Electric Power; (7) MCI—Ministry of Coal Industry.

3.2. The new regulatory system

The most important reform of the energy sector was implemented in 1998. These changes included a strategic reorganization of petroleum enterprises establishing a new vertically integrated management system for the oil industry. In 2002, China's power industry involved the separation of government functions from those of enterprises and the separation of power plants from lines operation. Fig. 5 illustrates the most recent government structure and regulatory system identifying the post-1998 situation [25]. The new structure is based upon three main goals: (i) removing government from the function of enterprise management; (ii) extending market-orientated energy system reform; (iii) improving the efficiency of the energy industry [26]. However, the key questions, as stressed by Andrews-Speed et al. [19] are the future function of the SETC, two new energy bureaus (SAPC—State Administration of Petroleum Corporation, and SACI—State Administration of Coal Industry) and the new Department for the power industry (SPCC—State Petroleum Corporation of China). According to Wu [25], their future functions seem unclear

3.3. Specific industry regulation

3.3.1. Coal regulation

The coal industry has been free of single corporation domination since the 1990s because of two natural features that constrain the development of China's coal industry. Firstly, most of China's coal reserves are in the north and far from coastal consumption

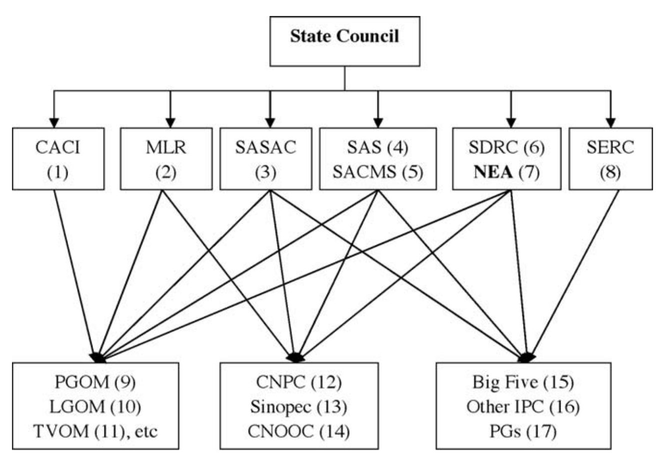

Fig. 5. New government structure and regulatory system for energy sector in 2008. *Note*: (1) CACI—China Association of Coal Industry. (2) MLR—Ministry of Land and Resources. (3) SASAC—State-owned Assets Supervision and Administration Commission of State Council. (4) SAWS—State Administration of Work Safety. (5) SACMS—State Administration of Coal Mine Safety. (6) SDRC—State Development and Reform Commission. (7) NEA—National Energy Administration in SDRC set up at August 8, 2008. (8) SERC—State Electricity Regulatory Commission. (9) PGOM—Provincial government owned mines. (10) LGOM—local government owned mines. (11) TVOM—Township and village owned mine enterprises. (12) CNPC—China National Petroleum Corporation. (13) Sinopec—China Petroleum and Chemical Corporation. (14) CNOOC—China National Offshore Oil Corporation. (15) Big Five—Huaneng Group, Datang Group, Huadian Corporation, Guodian Co. and Power Investment Co. (16) IPP—Independent Power Plant. (17) PGs—Power Grids.

regions and secondly, there is little rainfall in the main coal producing area. These two features make it a high priority for government to improve the transportation network and to enhance transport capacity. More importantly, coal is in surplus supply, in fact, the coal industry has often suffered from oversupplying. As a result, the government has often acquiescenced to coal production from various mines during periods of shortage and issued quotas during periods of excess supply [9].

The reform to the coal industry took a crucial step towards decentralization and disaggregation when the MCI was dismantled and replaced by the SACI, a newly created section within the SETC. Since 1999 the ownership and operation of central government owned mines (CGOM) has been transferred to the Provinces. Today, three main types of coal producers exist in China: (i) approximately 100 Provincial government owned mines (PGOM) which were transferred from the CGOM all of which are large scale with an annual output of 10 mmt; (ii) previously local government-owned mines (LGOM), including Provincial government owned mines; and (iii) town- and village-owned mines (TVOM) and private owned mines. According to Huang [27], there were 21,000 small mines in the LGOM, TVOM and private enterprises in 2005.

It is clear that under the new government structure and regulatory system there are no mines owned at the state level and all mines are owned and operated at and below the Provincial level. Consequently, the SACI is left as a purely regulatory body within government (Fig. 5) responsible for both policy and regulation together with its Provincial equivalents. Correspondingly, the SDPC is likely to retain some control over major investment decisions and the Ministry of Land and Resource (MLR) is likely to take overall responsibility for coal licensing.

3.3.2. Petroleum regulation

As discussed above, prior to 1998 China's petroleum industry was controlled by two state companies: CNPC and Sinopec, both of which combined the roles of government and enterprise management. However, after the 1998 strategic reorganization, the government functions of the petroleum sector were removed from the state companies and placed with SETC (Fig. 5). The assets of both CNPC and Sinopec were redistributed to create two regional, vertically integrated companies that spanned the full range of activities in the petroleum industry. The CNPC and Sinopec have now become 'pure' companies. The CNPC's territory covers the north and west of the country, while Sinopec's territory now lies in the south and east. Their previous government functions have now been assigned to SAPC, a newly created agency within SETC.

It appears from Fig. 5 that all companies in the petroleum industry are regulated directly by the SAPC within the SETC. Petroleum prices and transportation are regulated by two subdivisions, the Price Administration Division and Transportation Energy Division, within the SDPC. The MLR is responsible for issuing licenses.

3.3.3. Electricity regulation

Prior to 1985, China's electricity industry was under the control of central government [9]. The generation, transmission, distribution and retailing of electricity were all within the administration of the Ministry of Water and Power Industry. However, the power industry has experienced a series of changes since 1985 [28]. In 1988 the Ministry of Coal Industry, the Ministry of Oil Industry, the Ministry of Nuclear Industry and the Ministry of Water and Power were merged into a newly created Ministry of Energy (MOE), which was disbanded in 1993. This highly centralized power administration system didn't change fundamentally until 1997. However, during the interim, guidelines to separate the responsibilities of government and business were produced and provincial Bureaus of Electric Power were given some operational autonomy with local governmental jurisdiction over the development of the local power industry. The aim of these changes was to encourage investment in the power sector and promote the generation of electricity.

To free the sector of government intervention and create Vertically Integrated State-Owned Utilities (VISOU), the State Power Corporation (SPC) was created in March 1997. One year later, the Ministry of Electric Power was dismantled and its administrative functions assigned to a new department of the SETC.

The 1997–2002 reforms were mainly focused on the separation of government and enterprise as well as the separation of ownership and operation. However, the newly created SPC became another monopolist controlling 50% of the country's generation assets and most of the technology and development assets. As a result, it became a major obstacle to the development of a market-oriented power industry [29].

An important component of the market-oriented power reform process was to dismantle the SPC. In December 2002 its assets were divided into 11 new corporations, including two grid operators: the State Power Grid (SPG) and the China Southern Power Grid (CSPG),[3] five Independent Power Plants (The Big Five): Huaneng Group, Datang Group, Huadian Corporation, Guodian Corporation and Power Investment Corporation, and four auxiliary corporations: Power Generation Consulting Group Corporation; Hydropower Engineering Consulting Group Corporation; Hydraulic and Hydroelectric Construction Consulting Group Corporation and Gezhouba Group Corporation. The generation and transmission assets were not distributed among the 11 new corporations, but were directly managed and controlled by State Power Grid until 2006. Since then, those assets have been purchased by the State Electricity Regulatory Commission (SERC). Therefore, the regulatory framework has become one where the SDRC is responsible for planning, price, investment and regulation; the SERC is an independent regulator, and at the bottom (see Fig. 5) are the various enterprises. For more on the detailed reforms of China's power industry refers Wu [25], Xu and Chen [28], Wang [9], and Ma and He [29].

China Taiyuan Coal Exchange (CTCE) in Taiyuan was approved by State Council to be setup on 18 June 2007 to replace the coal ordering meeting between coal producers and power producers [30]. The toughest reform in China's energy industry has been settled since then. State Energy Administration (SEA), a division of State Development and Reform Commission, was established in July 2008. All these probably foresee that a full competitive energy market system has started to operate in China.

4. Capacity building of energy industry

Strong economic growth and rising income per capita have produced an increasing demand for energy. Therefore, the development of the energy industry has become an important item on the agenda of the Chinese government. Enhancing energy production is one element of meeting the demand for energy in China. Since the 1990s, China has invested significantly in increasing the capacity of the energy sector and, as a result, total new energy capacity has increased.

Table 1 shows the change in capacity building for coal, crude oil and electricity. In the 1990s, the newly increased capacity in coal extraction was, on average, only 23 mmt, which only accounted for 1.8% of the current year raw coal production. With rapidly increasing investment, however the newly increased capacity of

[3] State Power Grid includes five regional grids: Northwestern Grid, North Grid, Northeastern Grid, Central Grid, and East Grid and also referring to Fig. 7.

Table 1
Present new installed capacity and its percentage of total capacity (million tonne each year and million kW).

Year	Coal exploitation		Crude oil exploitation		Coal power plant		Hydropower station	
	Capacity	Δ%	Capacity	Δ%	Capacity	Δ%	Capacity	Δ%
1993	42.8	3.7	6.9	4.8	9.4	6.6	4.0	9.4
1994	9.5	0.8	6.2	4.3	8.1	5.2	4.2	8.3
1995	23.3	1.7	7.4	4.9	10.7	6.4	3.7	7.1
1996	16.9	1.2	9.0	5.7	13.6	7.4	3.7	7.1
1997	30.0	2.2	12.5	7.8	10.3	5.3	3.7	6.8
1998	9.7	0.8	8.4	5.2	15.4	7.9	6.2	10.8
1999	23.5	2.2	9.5	5.9	12.8	6.0	9.1	16.0
2000	22.6	1.7	9.2	5.6	13.4	5.8	4.5	7.3
2001	14.9	1.3	15.6	9.5	10.1	4.1	3.4	4.3
2002	34.2	2.5	25.4	15.2	33.2	12.0	5.2	6.5
2003	74.4	4.5	17.2	10.1	21.4	6.5	12.7	16.1
2004	154.4	7.8	24.7	14.0	37.0	9.9	11.1	11.3
2005	183.8	8.3	23.9	13.2	52.8	12.4	12.8	11.6
2006	226.5	9.5	16.0	8.7	80.2	16.2	13.0	10.7
Average								
1990s	22.2	1.8	8.6	5.5	11.5	6.4	4.9	9.4
2000s	101.5	5.1	18.9	10.9	35.4	9.6	9.0	9.7

Note: Coal power capacity was estimated by total coal electricity generation divided by 24 h/day) × 200 (day/year) and hydropower capacity was estimated by total hydroelectricity generation divided by 24 h/day × 150 days/year.
Data source: China Statistical Yearbook (2007) [17].

coal extraction reached, on average, 100 mmt, accounting for nearly 5.5% of current year raw coal production in the 2000s. The same pattern can be observed for crude oil extraction for example, the newly increased capacity of crude oil extraction averaged 9.3 mmt, accounting for 5.5% of current year crude oil production in the 1990s. Both doubled in the 2000s, reaching 18.9 mmt and 10.8%, respectively.

In the 1990s, newly installed capacity in coal powered plants was, on average, 11.5 million kW, being 6.4% of current year total installed capacity of coal powered plants nationwide. By the 2000s, newly installed capacity at coal powered plants reached 35.4 million kW, accounting for nearly 10% of current year total installed capacity of coal powered plants. Between 1993 and 1999, newly installed capacity at hydropowered stations was 4.9 million kW per year, while the newly installed capacity nearly doubled each year in the 2000s. Since 1992, the new capacity has been maintained at approximately 10% of current year total installed capacity for hydropower generation.

After observing the patterns of growth in capacity building in the energy industry, it can be noted that the growth of production capacity in raw coal extraction was slower than in crude oil extraction and electricity generation by coal powered plants and hydropower stations in China. Clearly the percentage of new capacity in current year total production capacity is only approximately 5% of raw coal extraction while it is closer to 10% in the other three energy sectors.

China's capacity building in the energy sector is, in general, able to meet its aggregate energy demand. However, there are significant differences across energy sources. For example, from 2000 to 2006, China's capacity for coal extraction averaged 1725 mmt, but its coal consumption only increased 179 mmt each year in the same period. Therefore, China actually ran a surplus of coal capacity building. Likewise, oil capacity building was 172 mmt each year from 2000 to 2006, but its actual increase in oil consumption was only 22 mmt in the same period.

5. Energy transportation

Uneven distribution of energy production and consumption across Provinces has produced pressure on the domestic transportation sector. This is particularly true for coal which accounts for 75% of total production where coal is consumed throughout China.

Inter-Provincial total shipment of coal is 2394 mmt, which amounts to 1820 billion metric tonnes km, and accounts for 75% of total rail cargo in 2006. Of total interprovincial coal shipments in 2006, outflows of coal accounted for 40% (993 mmt), and inflows 60%, (1400 mmt). Because of the uneven production and special types of coal, there are significant variations across Province in the volume of total interprovincial coal shipment. Table 2 presents data on the outflows and inflows of coal and the percentage of total coal shipped in total coal consumption. As can be seen from Table 2 Shanxi, Inner Mongolia, Henan and Shaanxi are major Provinces which export coal, 432, 145, 83 and 80 mmt respectively in 2006, (column 1). Major Provinces importing coal are Shandong, Hebei, Jiangsu and Zhejiang, where the total inflows were 188, 173, 158 and 112 mmt, respectively (column 2). Due to the uneven distribution of production and types of coal, total coal shipments in Shanxi Province amounted to 470 mmt being more than 150% of its total consumption within the Province in 2006 (columns 3 and 4). Total coal shipments were 200 mmt or 75% of total coal consumption within the Province of Hebei. There are several other Provinces where total coal shipments range from 110 to 160 mmt (Inner Mongolia, Jiangsu, Zhejiang and Henan).

A major feature of interprovincial coal shipments in China is that coal is shipped from West to East and from North to South. These flows are shown in Fig. 6. In particular, West–East includes: (1) Datong (in Shanxi Province) to Qinhuangdao (in Hebei Province); (2) Shenmu (in Shanxi Province) to Huanghua port (in Hebei Province); (3) Taiyuan (in Shanxi Province) to Dezhou (in Shandong Province); (4) Changzhi (in Shanxi Province) by Jinan to Qingdao; (5) Houma (in Shanxi Province) by Yueshan (in Henan Province), Xinxiang and Yanzhou (in Shandong Province) to Rizhao. North to South includes: (1) Harbin (in Heilongjiang Province) by Shenyang (in Liaoning Province), Dalian and Shanghai to Guangzhou (in Guangdong Province), including both railway and boats; (2) Tianjin by Jinan, Xuzhou (in Jiangsu Province) and Nanjing to Shanghai, including both railway and boats; (3) Datong (in Shanxi Province) by Taiyuan, Jiaozhuo (in Henan Province), Zhicheng (Hubei) and Liuzhou (in Guangxi Province) to Zhanjiang (in Guangdong Province); and (4) Baotou (in Shanxi Province) by Xi'an (Shaanxi) and Ankang (in Sichuan Province) to Chengdu.

The largest coal producer in China is in Shanxi Province where most coal is shipped to Hebei, Shandong, Tianjin, Jiangsu, Beijing and Liaoning Provinces and accounted for 90% of Shanxi's total outward shipments in 2006. The second largest is Inner Mongolia where a total of 120 mmt, accounting for 83% of total outflow shipments, was shipped to Liaoning, Tianjin, Heilongjiang, Jilin and Hebei Provinces in 2006. See Table 3 for data on other Provinces.

When we consider petroleum products they are also shipped throughout China. Major Provinces that export petroleum to other Provinces are Tianjin, Shanghai, Liaoning, Heilongjiang, Shandong and Xinjiang. In 2006, total outflow shipments of petroleum and products was 249 mmt, of which 42 mmt was shipped from Tianjin, 36 mmt from Shanghai, 30 mmt from each of Liaoning and Heilongjiang, 24 mmt from Shandong and 17 mmt from Xinjiang, all of which account for 71% of national total outflow shipment of petroleum and products. There are six Provinces that import petroleum and products of over 15 mmt from other Provinces. Of 291 mmt of inflow shipments of petroleum and products, 39 mmt was shipped to Shanghai, 35 mmt to Liaoning, 26 mmt to Tianjin, 23 mmt to Guangdong, 19 mmt to Beijing and 15 mmt to Shandong, all of which account for 54% of the national total inflow shipments of petroleum and petroleum products in the same year.

Table 2
The volume of interprovincial coal shipment in 2006, million metric tonnes.

Province	Outflow shipment	Inflow shipment	Total shipment	% of total consumption
Beijing	3.9	26.9	30.8	90
Tianjin	0.0	37.8	37.8	87
Hebei	28.9	173.3	202.2	75
Shanxi	431.6	39.5	471.1	153
Inner Mongolia	145.4	17.9	163.3	95
Liaoning	5.4	77.8	83.2	51
Jilin	4.7	51.8	56.4	71
Heilongjiang	35.1	11.5	46.6	50
Shanghai	1.8	53.3	55.0	95
Jiangsu	7.1	158.1	165.2	81
Zhejiang	0.0	112.1	112.1	96
Anhui	30.8	35.5	66.2	70
Fujian	2.1	31.4	33.5	59
Jiangxi	3.0	20.9	23.9	47
Shandong	28.1	187.9	216.0	70
Henan	83.3	49.9	133.2	60
Hubei	0.0	82.9	82.9	80
Hunan	8.3	34.8	43.1	42
Guangdong	0.0	98.1	98.1	85
Guangxi	10.6	36.7	47.3	102
Hainan	0.0	2.4	2.4	68
Chongqing	5.5	3.1	8.6	21
Sichuan	19.2	20.3	39.5	41
Guizhou	29.2	0.0	29.2	28
Yunnan	6.1	8.3	14.4	16
Tibet	–	–	–	–
Shaanxi	80.0	0.0	80.0	104
Gansu	9.1	10.4	19.5	44
Qinghai	0.0	3.8	3.8	38
Ningxia	11.1	14.2	25.3	70
Xinjiang	2.5	0.4	2.9	6

Note: Physical unit. Average distance of rail shipment was 760 km in the last decade.
Data source: China Energy Statistical Yearbook (2007) [13].

Fig. 6. China's coal transportation routes. *Note*: horizontal lines represent raw coal transported from West to East. Vertical lines represent raw coal transported from North to South.

Table 3
Major domestic railway coal shipment by origins and destinations in 2006.

Origin	Coal shipment (mmt)	Of total outflow (%)	Major destinations (Provinces)
Shanxi	390	90	Hebei, Shandong, Tianjin, Jiangsu, Beijing and Liaoning
Inner Mongolia	120	83	Liaoning, Tianjin, Heilongjiang, Jilin and Hebei
Henan	69	83	Hubei, Jiangsu, Shandong, Jiangxi and Anhui
Shaanxi	66	83	Hubei, Jiangsu, Shandong and Henan
Heilongjiang	34	99	Liaoning and Jilin
Hebei	23	81	Tianjin and Jilin
Shandong	20	74	Jiangsu and Zhejiang
Guizhou	18	64	Guangxi
Anhui	16	55	Jiangsu

Data source: China Transportation Yearbook (2007) [54].

China is apparently not rich in natural gas reserves. In fact, there are only a few Provinces that export natural gas. The total outflow shipments of natural gas was 18,244 million m^3 in 2006, while total transportation amounted to 8866 billion cubic meters km in conjunction with an average shipment distance of 486 km. The major exports come from a few Provinces the largest being Xinjiang (10,254 million m^3), followed by Sichuan and Shaanxi (5300 million m^3 each), and finally Inner Mongolia, Chongqing and Guangdong (3870, 3100 and 2460 million m^3, respectively). These Provinces account for 95% of the national outflow shipments of natural gas in 2006. Although gas is shipped throughout China, the variations across Provinces are highly uneven. In 2006 for example, inflow shipments of natural gas were 4057 million m^3 to Beijing, around 3000 million m^3 to Jiangsu, approximately 2000 million m^3 to Shanghai, and around 1000 million m^3 to Zhejiang, Henan and Gansu. These account for approximately 70% of the national inflow shipments of natural gas in 2006.

In contrast, electricity generation is widespread with more than 80% of demand met within Province, the exception being Beijing where only 35% of demand for electricity was met internally. As a result, only 11% of the demand for electricity is transmitted inter-provincially. The largest surplus of electricity was Inner Mongolia (coal based) and Hubei (hydro-based), each of which exported transmission of approximately 55 billion kWh. Other exporting Provinces in 2006 included Shanxi, 43 billion kWh (coal based); Guizhou 36 billion kWh (coal based), and Jiangsu 25 billion kWh. Most of the surplus electricity was transmitted to Guangdong (61 billion kWh), Beijing (41 billion kWh), and Hebei, Shanghai and Jiangsu (around 30 billion kWh for each), which accounted for over 70% of national inflow transmission of electricity in 2006.

In China there are seven electricity networks; Northwest, Xizang, North China, Central China, Southern China, Northeast and East China, and three major electricity transmission routes; Northern Route, Central Route and Southern Route. China's electricity is typically transmitted from West to East and from North to South. Fig. 7 shows China's electricity networks and transmission routes.

6. Energy price reforms and changes

Energy price reform is an integral part of the overall economic reform package in China. Fesharaki et al. [31] believe that energy prices were 'irrational' and caused enormous macroeconomic and microeconomic distortions in the energy sector and throughout the economy in China. However, the most important and interesting aspect is whether energy prices are still irrational and still cause macroeconomic and microeconomic distortions? In this section we firstly review the major policies of energy price adjustment and their corresponding effects. We will then consider the trends in energy prices for the major energy components focusing on the heterogeneity of price levels across Provinces. Finally, we use our new results to show how the energy market currently functions in China by considering the degree of energy market integration.

6.1. The characteristic of price reforms

Since the early 1980s, China has introduced numerous measures to rationalize oil, coal, gas and electricity prices. However, many of the measures were incremental and the scale small until 1993. The reason is that the strategy of energy price reforms that China adopted was gradual. In the initial years there might be little effort to move the economy to one in which resources and factors were allocated according market price signals [32]. As a result, there were not any losers in the initial years [33].

Until the reforms of the later 1970s, energy prices were fully state-controlled in China. During the early 1980s, China adopted a 'dual track' system of energy pricing policy, i.e., 'in-plan' prices and 'out-plan' prices. This energy pricing system remained in place until 1993. 'In-plan' energy prices were normally lower than market prices, while 'out-plan' energy prices were typically market prices. However, in-plan energy prices were not always fixed. Most in-plan prices dramatically increased as energy price reform processed after 1994 [6]. In-plan energy prices were gradually replaced with market-mediated prices [34]. This prepared the sector for government motivated market-oriented energy price reform.

6.2. Evolution of energy pricing policies

6.2.1. Coal price reform

The market-oriented energy price reform varied in time and in intensity across energy type. The 'dual track' pricing system for

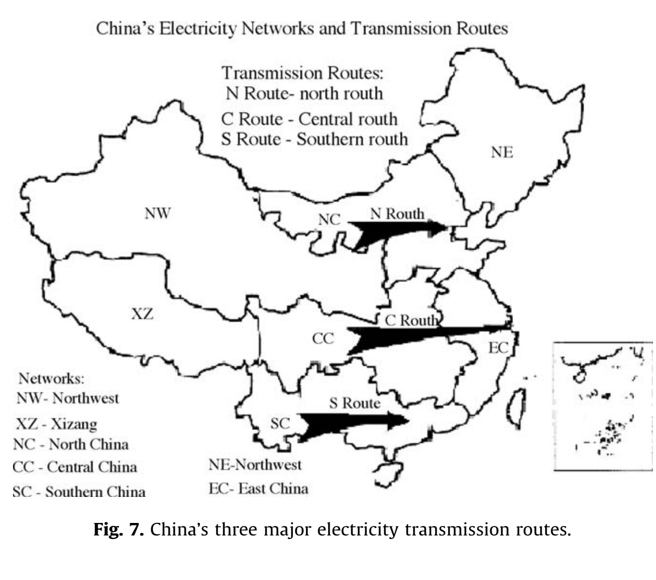

Fig. 7. China's three major electricity transmission routes.

coal was introduced **in 1985**. Under this policy, CGOMs were given an output quota at low price for unified allocation to those important state-owned downstream industries such as electricity, steel, metallurgy, engineering, chemical and transportation. The LGOMs and TVOMs were also given quota. Coal within quotas was referred to as 'in-plan' and above quotas was referred to as 'out-plan'. The output above the quotas could be priced 50% higher and the output above more could be priced 100% higher than within quotas [35].

As more and more coal was sold on free market, the deliberate low price of 'in-plan' coal was difficult to sustain. It confronted with great pressure to recover to market level, which caused little complain from most of downstream industries because their market and price have been gradually freed. Therefore, price regulation on coal was completely abolished after 1994.

As electricity tariffs were still tightly controlled, some power plants could not afford coal with market price and some coal enterprises refused to sell coal to power plants. As a result, a new policy was established in 1996 that the prices of coal sold to power plants were guided by central government again and announced at the end of every year. However, this policy could not be implemented perfectly because coal producers did not fully perform their contracts with many excuses [9]. In addition, the contracts sometimes aborted due to transportation unavailable. Consequently, the electricity industry could not always meet its coal demand under guided prices. Under this circumstance, the disputes and blackout happened frequently between coal producers and power plants.

The bargaining between two parties became even more severe after 2002 when government-guided price of coal was once announced to be cancelled but electricity tariffs still remained regulated. This means that coal producers were allowed to determine coal price at their will. As a result, only 90 mmt, which was 37% of total amount of demand for coal, were contracted at 2002. The central government as a mediator was in a dilemma at the first time. Faced with serious power shortage, in April 2003 NDRC gave an order, in which the price was just midpoint between requirements of two parties, and in 2004 government introduced a new coal pricing policy, which was called 'co-movement' of prices of both coal and electricity. The co-movement is not a free market adjustment but regulated and determined periodically by the SDRC to avoid extreme price fluctuation. Adjustment will only be made if fluctuation of coal price exceeds 5%, otherwise, the change will be accumulated into the next adjustment period [29].

China Taiyuan Coal Exchange (CTCE) was established on 18 June 2007 [30], which is replace the coal ordering meeting between coal producers and power producers. Since then, more freedom would be given to coal suppliers and consumers, implying that the toughest reform in China's energy industry has been settled and a full competitive energy market was expected to operate in China.

6.2.2. Petroleum price reforms

Petroleum price regulation has experienced four stages. Pre-1981, petroleum prices were fully state-controlled. From 1981 to 1994, 'dual track' pricing system was adopted, while from 1994 to 1998 petroleum prices were market meditated. After 1998, domestic petroleum prices have been set in accordance with the international energy market price [34]. Meanwhile, central government sets the regional prices of refined oil products according to Singaporean oil market and as a result, the 1998 reform had domestic oil prices very close to international prices [25].

6.2.3. Electricity price reforms

Electricity pricing reform is complicated in China. As in other countries, electricity prices are not completely deregulated in China, however, the government has made significant progress to raise electricity prices to 'realistic' market levels since the beginning of economic reform.

In 1985, electricity tariffs were raised throughout the country. For the first time, locals were allowed to raise tariffs to cover the rising costs of coal and transportation [34]. The State Council also encouraged investment in power industry and executed multi-tiers of electricity tariffs. In 1987, the government issued a new policy of *Fuel and Transportation Add-up*. It was used as an adjustable surcharge on catalog prices based on fluctuations in coal and transportation costs. This pricing adjustment procedure was administered and assessed annually by the SDRC.

In 1991, a 'high-in' and 'high-out' policy was introduced, allowing electricity tariffs to fluctuate according to coal and other factor costs. In 1993, a 'new plant-new price' policy was implemented, which allowed all power plants built after 1992 to sell power to provincial power companies at debt repayment prices in order to provide sufficient revenue for the repayment of loan capital with interest. In the 1990s, a range of surcharges, such as '*Power Construction Fund*', '*Three Gorge Construction Fund*', were imposed [29]. With these new policies, electricity tariffs have risen rapidly [36]. However, these new policies also resulted in a complicated price structure, leading a high regulatory, supervisory and transaction cost.

To simplify and control the price, a new price scheme, operation-period price and yardstick price, was adopted in 1997. The price under this scheme is based on an average social generation cost and a unified internal rate of return on capital over the remaining operation period. For present plants, this is indeed an operation-period price while for new plants the new scheme actually specifies a unified yardstick price.

Some new policies were introduced after 2002. 'Operation-period price and yardstick price' are still used in regions where competitive regional wholesale market was not established after 2002. For regions where competitive wholesale transaction has been introduced, the price consists of two components: capacity price which is determined by the government according to the average cost of all generation units in the market, and volume price which is determined competitively in the market.

On the retail side, the catalog was simplified to include: (i) a unit price scheme used for residential and agricultural sectors; (ii) a two-component price scheme, similar to the counterpart on generation side, used by the industrial and commercial sectors; (iii) '*tidu jiage*' (a kind of variable price)[4] prices were also introduced after 2004; (vi) higher prices charged for energy-intensive industries [29]. To reflect rising coal cost, 'co-movement' price of coal and electricity is used for various electricity prices.

6.3. The changes of energy prices

China's energy prices have experienced several energy policy adjustments during the last three decades and the prices of major primary energy sources are apparently converging over time. China's energy prices appear to be rising and dependent more and more upon with those in other international markets [25,34]. However, at the Regional and Provincial level energy price heterogeneity appears to remains endemic for some forms of energy.

6.3.1. Historical observation

To illustrate these issues, consider Table 4, which displays the spot prices and their changes over time for four major energy fuels in China. Several features can be observed. Firstly, energy prices were very stable during the late 1990s. They rose rapidly, however,

[4] This price is a kind of variable price decided based on current quantity consumed and used to encourage or restrain electricity consumption.

Table 4
National aggregate energy price 1995–2005.

Year	Coal (¥/tonne)	Electricity (¥/kWh)	Gasoline (¥/tonne)	Diesel (¥/tonne)
1995	214	38	2772	2293
1996	231	38	2773	2306
1997	264	40	2876	2612
1998	260	45	3240	2451
1999	247	46	2870	2530
2000	241	48	3640	3305
2001	240	50	3685	3229
2002	261	51	3571	3177
2003	283	54	4154	3516
2004	366	56	4730	3913
2005	414	58	5455	4501
1995–2005				
%Change	93	54	97	96
%Growth rate	6.8	4.4	7.0	7.0

Data source: calculated by taking the average of 10-day interval spot price time series published by State Development and Reform Committee of China.

in the new millennium for example, gasoline and diesel prices were below 2500 RMB per tonne in the late 1990s, but they immediately rose to over 3600 and 3300 RMB per tonne, respectively, in 2000. They quickly climbed to over 5400 and 4500 RMB per tonne by 2005. Similar scenarios can be found for coal and electricity. Secondly, prices for coal and oil are very consistent with a similar pattern of price change over time. Thirdly, electricity prices seem to be an exception. Its price level rose by nearly 55% and changed at a lower growth rate (only 4.4%) during the period. This may suggest that electricity prices were not consistent with those of other three energy sources or that electricity prices may not be cointegrated with those of other three energy sources, as a consequence of government control. This is an issue we will return to later.

How fast did energy prices changed over time? Are energy price changes consistent with other factors of production or the consumer price index?

It is useful to compare Chinese trends in energy price changes with those internationally and to consider the degree of market integration which is an important commitment within the WTO. As coal is the most important fuel in China, we take it as an example for comparative purposes. If we compare the cif price of Japanese steam coal imports [15] and China's coal spot price [37] for the period of 1995–2005, we find, see Fig. 8, that after 1998 the coal prices in Japan and China were very consistent despite apparent differences before 1999. This illustrates how China's coal price has converged to that of the international energy market this century. A similar pattern of coal price change can be observed between China–Northwest Europe and between China–US Central according to BP [15].

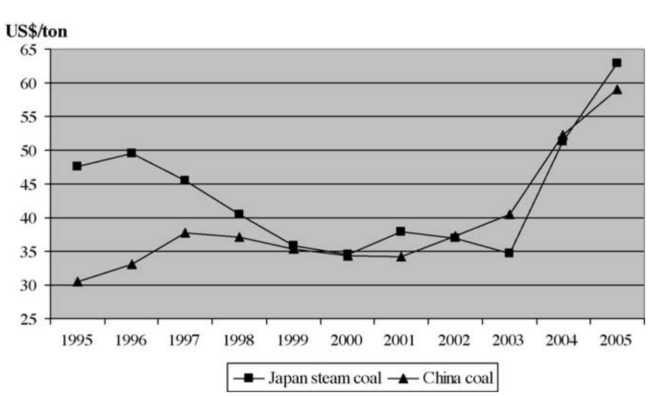

Fig. 8. Japan steam coal import cif price and China's coal spot price 1995–2005. *Note*: exchange rate of US$ to RMB is 7.0. *Data source*: BP 2008 [15] and National Development and Reform Committee, PRC.

6.3.2. Spatial observations

It is perhaps not surprising that the levels of energy price and the patterns of price changes show considerable variation across Provinces given the significant variations in economic growth. Table 5 shows the spot prices in 2005 and the changes from 1995 for four major energy sources over 31 Provincial (municipal or autonomous regional) capital cities in Mainland China. It can be seen from Table 5 that the spot price of coal varies considerably and the patterns of price change are also quite different across cities for example, the spot price of coal is over 630 RMB per tonne in the East (Shanghai and Nanjing), while it is below 200 RMB per tonne in the West (Lanzhou and Urumqi). The spot price of coal rose over 3 times in Chongqing, over twice in Taiyuan, and over 1.5

Table 5
Fuel prices and change (%) from 1995 by provincial capital cities.

Provincial capital city	Coal (¥/tonne)		Electricity (¥/kWh)		Gasoline (¥/tonne)		Diesel (¥/tonne)	
	2005	Δ%	2005	Δ%	2005	Δ%	2005	Δ%
Beijing	408	172	63	87	5345	88	4373	93
Tianjin	370	114	62	56	5486	96	4533	123
Shijiazhuang	387	165	56	33	5469	101	4533	106
Taiyuan	389	227	45	88	5534	116	4549	109
Hohhot	296	104	52	29	5491	96	4539	98
Shenyang	397	61	61	131	5357	103	4556	99
Changchun	475	147	67	86	5270	87	4323	90
Harbin	321	69	56	100	5107	79	4432	94
Shanghai	632	150	71	27	5544	102	4513	94
Nanjing	634	141	68	15	5292	118	4077	90
Hangzhou	501	75	72	30	5502	108	4430	93
Hefei	559	136	57	81	5333	90	4554	94
Fuzhou	523	87	65	6	5592	83	4435	84
Nanchang	374	58	58	95	5297	82	4489	94
Jinan	552	115	56	182	5395	109	4579	112
Zhengzhou	370	123	50	102	5330	85	4566	99
Wuhan	426	106	57	32	5210	81	4406	93
Changsha	490	87	59	36	5367	92	4411	94
Guangzhou	467	69	72	29	5422	102	4361	106
Nanning	369	41	56	135	5476	84	4517	83
Haikou	370	10	60	22	5779	109	4576	86
Chongqing	537	327	57	92	5666	99	4570	74
Chengdu	358	99	58	123	5631	119	4518	116
Guiyang	313	148	49	−32	5614	92	4606	86
Kunming	411	183	50	61	5682	97	4606	93
Lhasa	370	50	56	88	6410	143	5242	129
Xi'an	245	24	52	9	5390	97	4501	100
Lanzhou	168	−17	48	28	5440	96	4556	98
Xining	241	46	42	190	5099	83	4557	102
Yinchuan	270	132	47	12	5404	93	4504	108
Urumqi	135	−24	48	99	5082	99	4360	138

Data source: calculated by taking the average of 10-day interval spot price time series published by State Development and Reform Committee of China.

times in many places from 1995 to 2005. However, the spot price of coal only increased by 25% in Haikou and Xi'an; less than 50% in Nanning, Lhasa and Xining during the same period. The spot price of coal actually declined in Lanzhou and Urumqi, perhaps due to the characteristics of coal itself.

However, the opposite pattern can be found for gasoline and diesel. The spot prices across cities are at the same levels for both gasoline and diesel at around 5300 and 4300 RMB per tonne, respectively. The price changes are also similar across cities. The price almost doubled in all cities during the study period. There are only a few exceptions for example, the spot price of gasoline spot price increased by less than 80% in Harbin, Wuhan and Changchun, but more than 140% in Lhasa. Likewise, the spot price of diesel increased by less than 75% in Chongqing, but more than 130% in Lhasa and Urumqi.

7. China's energy efficiency

Energy intensity is an important indicator of energy efficiency, which is directly related to economic growth and energy consumption. To ascertain the change in China's energy intensity over time, Fig. 9 shows national aggregate GDP (in 1978 price), aggregate energy consumption and energy intensity measured as the ratio of energy consumption to GDP, since 1978. It appears that energy intensity has generally declined since 1978 while the trend has varied over time. This may suggest that the rates of energy intensity change frequently. It is also clear that since 2000 a different pattern has emerged.

If once considers energy intensity by sector, since 1980, see Table 6, one can observe some similarities and some differences. Firstly, the patterns of aggregate energy intensity shown in Fig. 9 and of industrial energy intensity shown in Table 6 are consistent as both industrial energy consumption and output (GDP) comprise most of the aggregate economy. The similar features of stable yet fluctuating energy intensity can be found after 2000 for industrial energy intensity (Table 6). Similar patterns can be observed for other sectors. However, more apparent and stronger rising trends appear for the other four sectors. For example, intensity rose from 0.64 in 2001 to 0.76 in 2006 for the transportation sector; from 0.12 in 2001 to 0.19 in 2006 for the construction sector. Whether these rising trends will maintain in the longer period is unclear, in part they may depend on any changes in energy policies.

What might have induced the changes in China's energy intensity? Ma et al. [38] survey the literature on China's energy economy and conclude that declining industrial energy intensity plays an important role in the decline in national aggregate energy intensity before 2000 and that rising industrial energy intensity plays an important role in increasing national aggregate energy intensity after 2000. This finding, however, does not identify the factors driving the change in energy intensity. To fill this gap, Ma et al. [38] estimate a translog cost function using a panel of provincial data for China and they conclude that 'technological change' has driven the increase in energy intensity and factor prices play little role in this process. Specifically, it is energy-using technologies that have been employed in this new millennium in China. If this finding is correct, the implications for current policies on technological and capital investment need to be seriously analyzed by China's decision-makers.

The changes in energy intensity are also not homogenous across regions, territories or Provinces. Table 7 shows Provincial aggregate energy intensity and its changes over the period 2001–2006 (based on 1978 prices) allowing comparisons to be made between Tables 6, 7 and Fig. 9.

Table 6
The Changes of national energy intensity by sector.

Year	Agriculture	Industry	Construction	Transportation	Commerce
1980	0.44	1.98	0.54	1.41	0.20
1985	0.25	1.62	0.43	1.11	0.11
1990	0.25	1.38	0.29	0.86	0.16
1991	0.25	1.27	0.28	0.81	0.15
1992	0.24	1.12	0.25	0.79	0.15
1993	0.22	1.00	0.20	0.77	0.19
1994	0.22	0.91	0.18	0.72	0.17
1995	0.23	0.87	0.16	0.67	0.17
1996	0.23	0.81	0.16	0.62	0.18
1997	0.23	0.72	0.13	0.71	0.17
1998	0.21	0.63	0.16	0.70	0.17
1999	0.21	0.55	0.13	0.70	0.18
2000	0.20	0.50	0.13	0.70	0.17
2001	0.21	0.44	0.12	0.64	0.17
2002	0.22	0.48	0.13	0.67	0.17
2003	0.21	0.49	0.12	0.72	0.18
2004	0.23	0.53	0.21	0.75	0.20
2005	0.23	0.52	0.19	0.74	0.19
2006	0.23	0.52	0.19	0.76	0.19

Note: Energy intensity (tonne/¥1000) = energy consumption (10k tonne)/GDP (¥100 million in 1978 price).
Data source: China Statistical Yearbook (1996–2007) [17], China Energy Statistical Yearbook (2007) [13].

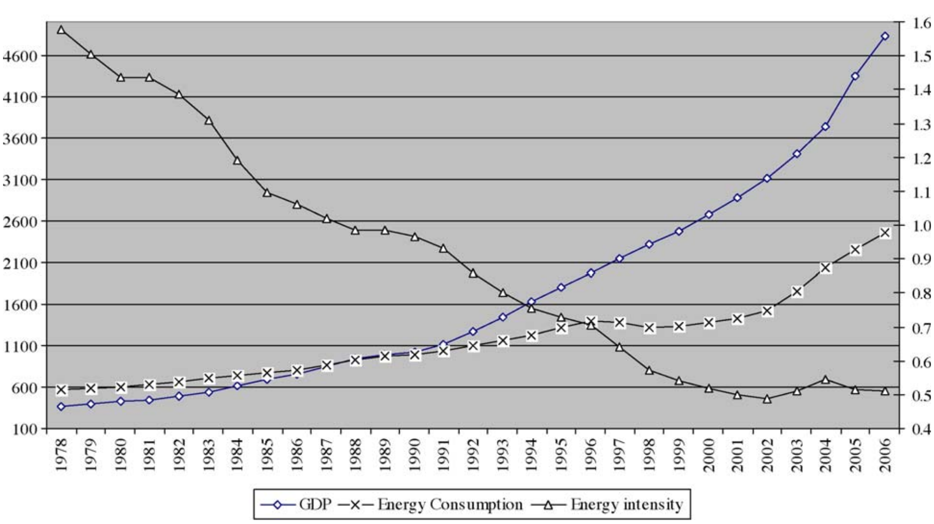

Fig. 9. National GDP (billion, 1978 price), aggregate energy consumption (million tonne standard coal), and aggregate energy intensity (tonne/¥1000). *Data source*: China Statistical Yearbook [17]. *Note*: Left-hand *y* axis is for GDP and energy consumption, and right hand *y* axis is for aggregate energy intensity.

Table 7
Aggregate energy intensity over Provinces in 1996, 2001 and 2006 and change.

Province	1996	2001	2006	% Change	
				1996–2001	2001–2006
Beijing	0.97	0.66	0.35	−32.0	−46.7
Tianjin	0.97	0.69	0.49	−28.9	−29.4
Hebei	1.11	0.81	0.88	−26.8	7.6
Shanxi	2.26	1.96	1.34	−13.3	−31.6
Inner Mongolia	1.23	1.15	1.10	−6.5	−4.7
Liaoning	1.33	0.93	0.81	−30.2	−12.6
Jilin	1.34	0.83	0.73	−38.1	−12.2
Heilongjiang	1.05	0.74	0.66	−29.5	−10.3
Shanghai	0.71	0.51	0.41	−27.5	−20.7
Jiangsu	0.58	0.41	0.41	−29.7	0.0
Zhejiang	0.50	0.42	0.40	−16.0	−6.5
Anhui	0.83	0.68	0.54	−18.1	−20.0
Fujian	0.40	0.32	0.42	−19.6	30.2
Jiangxi	0.61	0.47	0.47	−23.4	0.5
Shandong	0.66	0.46	0.56	−30.3	21.1
Henan	0.78	0.64	0.61	−17.8	−4.2
Hubei	0.87	0.57	0.67	−34.7	18.2
Hunan	0.89	0.51	0.61	−42.9	21.2
Guangdong	0.51	0.42	0.36	−18.2	−15.0
Guangxi	0.56	0.52	0.54	−6.1	2.9
Hainan	0.38	0.42	0.41	9.3	−2.1
Chongqing	0.00	0.75	0.64	–	−15.4
Sichuan	0.96	0.67	0.68	−30.1	1.6
Guizhou	2.20	1.79	1.45	−18.9	−18.7
Yunnan	0.80	0.74	0.78	−7.9	6.2
Tibet	0.00	0.00	0.00	–	–
Shaanxi	1.29	0.77	0.61	−40.1	−20.3
Gansu	1.69	1.18	0.98	−29.8	−17.1
Qinghai	1.63	1.35	1.40	−17.4	3.5
Ningxia	1.78	0.00	1.86	−100.0	–
Xinjiang	1.52	1.03	0.94	−32.3	−9.1

Note: calculated based on 1978 price, tonne/¥1000.
Data source: China Statistical Yearbook [17] and China Energy Statistical Yearbook [13].

As can be seen from Table 7 substantial variation in energy intensity, in both the levels and changes, can be seen across the Provinces for example, energy intensity is low in Beijing, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong and Hainan. These Provinces are located in the east and south of China and are part of the developed areas. On the other hand, in 2006, energy intensity is relatively high in the less developed area, for example, it measures over 1.4 in Guizhou, Ningxia and Qinghai, and about 1.0 in Gansu and Xinjiang. These Provinces are in the less developed Western region. Energy intensity is also greater than 1.0 in Shanxi and Inner Mongolia which are in the less developed Northern region. In contrast, energy intensity is less than 0.5 in the developed regions in the East and South (e.g., Beijing, Tianjin, Shanghai, Jiangsu, Guangdong and Hainan).

The trends in energy intensity also vary across the Provinces. Energy intensity declined by approximate 50% from 2001 to 2006 in Beijing and by 30% in Tianjin and Shanxi. However, it rose by 30% in Fujian and 20% in Shandong, Hubei and Hunan. It appears that energy intensity and economic growth are closely correlated. Therefore, national energy policies may not be suitable for provincial realities. As a result, provincial energy intensity may need to be studied and regional energy policy developed.

To improve energy efficiency, many projects have been introduced over the past 25 years. Price et al. [39] review China's energy efficiency policies from 1949 to 2000. They explain China's energy efficiency programs, examine the development of a comprehensive energy policy and assess existing energy conservation, regulation and policies. However, China's energy efficiency is still fairly low relative to other developed countries and regions. For example, China's large and medium enterprises consumed 181 kg standard coal equivalent to produce 1 tonne of cement in 2003, while Japan consumed only 128 kg standard coal equivalent in the same year; China consumed 890 kg standard coal equivalent to produce 1 tonne ethylene in 2003, while Japan consumed 629 kg standard coal equivalent to produce 1 tonne ethylene in the same year; the loss ratio of electricity transmission and distribution in Mainland China was 6.8%, but only 4.8% in Taiwan in 2005 [13]. As a result, energy intensity remained high at about 0.90 tonne oil equivalent per thousand US$ GDP (measured in 2000 US$ price) in Mainland China, whereas the world average was only 0.31 tonne oil equivalent per thousand US$ GDP (measured in 2000 US$ price) post-2002. Mainland China's energy intensity is approximate three times higher than the World average.

8. Energy supply, demand and trade

8.1. Primary energy supply and demand

8.1.1. Fossil fuel-based energy

China's energy production and consumption has increased since 1985 due in the main to its high economic growth rate. Table 8 shows China's energy production and consumption as well as its composition. There appear to be three distinct periods of energy production during the last two decades. During the decade 1985–1995, the growth rate of energy production is approximately 4% per annum. This is followed during the period 1995–200 by a period of stagnation from. From 2000 production soars at an annual rate of growth of approximately 9.0%. The composition of primary energy production, however, changed little. Coal continues to dominate primary energy production with a share of over 76.7% in 2006. The share of oil production has obviously declined over time and this has accelerated post-2000. Natural gas and other primary energy production have increased, but with fluctuations. The share of natural gas in primary energy supply, for example, remained approximately constant from 1985 to 1995.

Table 8
China's energy production and consumption (million tonne standard coal).

Year	Aggregate	Of which (%)			
	Production	Coal	Oil	Natural gas	Others
1985	855.5	72.8	20.9	2.0	4.3
1990	1039.2	74.2	19.0	2.0	4.8
1995	1290.3	75.3	16.6	1.9	6.2
2000	1289.8	72.0	18.1	2.8	7.2
2005	2058.8	76.5	12.6	3.2	7.7
2006	2210.6	76.7	11.9	3.5	7.9
Growth rate annually (%)					
1985–1990	4.0	0.4	−1.9	0.0	2.2
1990–1995	4.4	0.3	−2.7	−1.0	5.3
1995–2000	0.0	−0.9	1.7	8.1	3.0
2000–2005	9.8	1.2	−7.0	2.7	1.4
2005–2006	7.4	0.3	−5.6	9.4	2.6
Year	Consumption	Coal	Oil	Natural gas	Others
1985	766.8	75.8	17.1	2.2	4.9
1990	987.0	76.2	16.6	2.1	5.1
1995	1311.8	74.6	17.5	1.8	6.1
2000	1385.5	67.8	23.2	2.4	6.7
2005	2246.8	69.1	21.0	2.8	7.1
2006	2462.7	69.4	20.4	3.0	7.2
Growth rate annually (%)					
1985–1990	5.2	0.1	−0.6	−0.9	0.8
1990–1995	5.9	−0.4	1.1	−3.0	3.6
1995–2000	1.1	−1.9	5.8	5.9	1.9
2000–2005	10.2	0.4	−2.0	3.1	1.2
2005–2006	9.6	0.4	−2.9	7.1	1.4

Data source: China Statistical Yearbook (1996–2007) [17].

The growth rates of natural gas share in total primary energy supply varied considerably, rising to 8.1% from 1995 to 2000, declined to 2.7% in the next 5 years and then rose to 9.4% post-2005 (Table 8). Other primary energy production shares increased at an average of approximately 3% annually.

As for the energy consumption, a similar scenario can be found for aggregate primary energy consumption and composition. The only difference is that with a higher growth rate for aggregate primary energy consumption the role of coal has seen a decline, from over 75% in the 1980s and the 1990s approximately to 70% by 2006.

8.1.2. Hydropower and nuclear energy

It can be seen from Table 8 that China's renewable energy supply is very limited. In spite of a high growth rate, the share of renewable energy supply has remained low. In 2006 it was only 8% of the total primary energy supply. Of the renewable energies, hydropower and nuclear energy are two of the most important for China. China's hydropower production has grown rapidly during the last decade, from 1906 billion kWh in 1995 to 4829 billion kWh in 2007. This represents an annual growth rate of approximately 8%. Nuclear energy has grown even faster from 12.8 billion kWh in 1995 to 62.9 billion kWh in 2007, representing an annual growth rate close to 15%. However, as shown previously, the shares of both hydropower and nuclear energy are very small in total electricity generation. The former is 14.7%, while the later is less than 2.0% in 2007 [15].

8.1.3. Rural biomass consumption

Biomass energy has been playing the most important role in residential energy demand of rural China and has made a great contribution to alleviate the pressure of fossil energy supply of the country. Rural biomass energy consumption (only including firewood, crop stalks and biogas) in Mainland China was 206 million tonnes coal equivalent in 2000 and it rose to 280 million tonnes coal equivalent in 2006. Biomass energy accounts for overwhelming share in total rural energy consumption. Its share in rural aggregate energy consumption was 76% in 2000 and still maintained 74% in 2006. Of biomass energy crop stalk accounts for over 60% [13].

8.1.4. Fossil energy consumption by industry

Industry remains the nation's largest consumer of primary energy. However, as other sectors have expanded its share of primary energy consumption has declined from close to 80% in the 1980s to approximately 70% by 2006 (Table 9). Likewise, agriculture's share of primary energy consumption has also declined from approximately 8% in the mid-1980s to around 3.5% in 2006.

It is worth noting the sharp growth of shares in consumption from the transportation and commercial sectors during the last two decades. Transportation was a very small consumer in 1985, only 1.5% and the commercial sector close to 1%. However, since 1985, their shares have grown considerably for example, the share of primary energy consumption in the transportation sector increased to 4.5% in the 1990s and then climbed to 7.5% by 2006. At the same time, the share of primary energy consumption more than doubled from barely 1% in 1985 to 2.2% by 2006 in the commercial sector. It is clear that currently these two sectors now account for approximately 10% of the total national primary energy consumption.

Since 1990, the residential sector has become the second largest consumer of primary energy in China. Its share of primary energy consumption was only 5.4% two decades ago in 1985. Five years later, it jumped to 16.0%. Since 1995 when industrial output began to recover the residential share of consumption has been remained stable at approximately 10%.

By observing growth rates one may be better able understand how the structure has changed over time and over sectors (Table 7, bottom section). Some observations can be made. Firstly, except for a short period of recovery (1995–2000), a sharply declining share of agricultural sector energy consumption has been evident from 1985 to 2006 Secondly, a rapidly declining rate only occurred in the 1980s and since then the growth has not changed much until 2006 for industry; Thirdly, the construction sector has experienced three different phases of growth with effects on its share of energy consumption. The first was a sharply declining rate of energy consumption share for the period 1985–1990 to 1990–1995. This was followed by an extreme move in the opposite direction 1995–2000. Since then the situation is one of stability. Fourthly, the transportation sector has also experienced three phases of share growth. The fastest growth of share occurred during the period 1985–1990 (over 25%) followed by high growth 1995–2000 with the third phase being no share growth in all other periods; fifthly, a similar share growth rate pattern can be found for the commercial sector where there was first rapid growth, then some decline and finally stability post-2000; Finally, the growth of the residential share of energy consumption is clearly related to the extraordinarily economic growth (24.3%) that occurred during the period 1985–1990. This is clearly unsustainable in the longer term.

8.1.5. Fossil energy supply and demand across regions

China's primary energy production and consumption varies across Provinces and this causes significant domestic trade within China. Table 10 presents data for 2006 on the production and consumption of coal and oil, and the surplus by Province. Firstly, note the largest coal producing Province is Shanxi (North)

Table 9
Shares of aggregate energy consumption by sector in China.

Year	Agriculture	Industry	Construction	Transportation	Commerce	Others	Resident
1985	7.7	79.7	1.7	1.5	0.9	3.0	5.4
1990	4.9	68.5	1.2	4.6	1.3	3.5	16.0
1995	4.2	73.3	1.0	4.5	1.5	3.4	12.0
2000	4.4	68.9	1.5	7.3	2.2	4.2	11.5
2004	3.8	70.5	1.6	7.4	2.4	3.9	10.5
2005	3.6	71.0	1.5	7.4	2.2	3.9	10.4
2006	3.4	71.1	1.5	7.5	2.2	3.9	10.3
Growth rate annually (%)							
1985–1990	−8.6	−3.0	−6.7	25.1	7.6	3.1	24.3
1990–1995	−3.0	1.4	−3.6	−0.4	2.9	−0.6	−5.6
1995–2000	0.9	−1.2	8.4	10.2	8.0	4.3	−0.8
2000–2005	−3.9	0.6	0.0	0.3	0.0	−1.5	−2.0
2005–2006	−5.6	0.1	0.0	1.4	0.0	0.0	−1.0

Data source: China Statistical Yearbook (1996–2007) [17].

Table 10
Provincial balance of coal and oil in 2006, million tonnes.

Province	Production		Consumption		Surplus	
	Coal	Crude oil	Coal	Crude oil	Coal	Crude oil
Beijing	6.5	–	30.6	8.0	−24.1	−8
Tianjin	–	19.4	38.1	9.0	−38.1	10.4
Hebei	83.6	6.1	213.5	10.5	−129.9	−4.4
Shanxi	581.4	–	283.5	–	297.9	–
Inner Mongolia	297.6	–	161.9	1.4	135.7	−1.4
Liaoning	73.7	12.3	142.1	55.6	−68.4	−43.3
Jilin	30.0	6.8	75.5	9.5	−45.5	−2.7
Heilongjiang	102.8	43.4	90.3	18.5	12.5	24.9
Shanghai	–	0.2	51.4	18.3	−51.4	−18.1
Jiangsu	30.5	1.9	184.3	23.0	−153.8	−21.1
Zhejiang	0.2	–	113.3	21.1	−113.1	−21.1
Anhui	83.3	–	88.3	4.5	−5	−4.5
Fujian	19.3	–	54.0	3.8	−34.7	−3.8
Jiangxi	27.8	–	45.9	4.2	−18.1	−4.2
Shandong	140.7	27.6	290.0	38.8	−149.3	−11.2
Henan	195.3	4.9	210.0	7.0	−14.7	−2.1
Hubei	11.2	0.8	96.5	8.5	−85.3	−7.7
Hunan	59.5	–	94.4	5.7	−34.9	−5.7
Guangdong	–	13.4	111.3	28.1	−111.3	−14.7
Guangxi	6.8	–	41.7	1.2	−34.9	−1.2
Hainan	–	0.1	3.3	2.3	−3.3	−2.2
Chongqing	39.9	–	37.3	–	2.6	–
Sichuan	86.0	0.2	85.3	1.7	0.7	−1.5
Guizhou	118.2	–	99.4	–	18.8	–
Yunnan	73.4	–	74.8	–	−1.4	–
Tibet	–	–	74.0	14.9	−74	−14.9
Shaanxi	182.6	19.9	39.6	13.2	143	6.7
Gansu	39.5	0.8	9.1	1.1	30.4	−0.3
Qinghai	6.9	2.2	34.9	1.7	−28	0.5
Ningxia	32.7	–	44.4	18.1	−11.7	−18.1
Xinjiang	43.2	24.7	30.6	8.0	12.6	16.7

Data source: China Energy Yearbook 2007 [13].

producing approximately 580 mmt, followed by Inner Mongolia (North) with approximately 300 mmt., and the third largest are Henan (Central) and Shaanxi (West) with approximately 200 mmt. There are several other Provinces including Heilongjiang (Northeast), Shandong (East) and Guizhou (Southwest), whose coal production is approximately 100 mmt. Secondly, crude oil production is very small with many Provinces registering no production. The largest oil field is currently located in Heilongjiang (Northeast), with production of 43 mmt, followed by Shandong (East) with 30 mmt. Twenty mmt oil fields are found in Tianjin (East), Shaanxi (West) and Xinjiang (Northwest) while 10 mmt oil fields are found in Liaoning (Northeast) and Guangdong (South). Thirdly, coal and oil are consumed throughout China for example, Shanxi and Shandong consume nearly 300 mmt of coal and Hebei (North), Jiangsu (East) and Henan (Central) consume approximately 200 mmt of coal. There are many Provinces that consume 100 mmt of coal. However, not all Provinces consume crude oil. The largest consumer of crude oil is Liaoning (55 mmt), followed by Shandong (approximate 40 mmt), and the third is Guangdong (close to 30 mmt). There are several Provinces that consume 20 mmt of crude oil. Fourthly, it is clear that most, but not all, Provinces run a 'deficit' of coal for example, Shanxi, Inner Mongolia and Shaanxi run a 130-300 mmt surplus while Heilongjiang, Guizhou, Guangxi, Gansu and Xinjiang have a surplus of something like 30 mmt. The large coal inflow Provinces are Jiangsu, Shandong, Hebei, Zhejiang and Guangdong, with a deficit of between 150 mmt to 100 mmt respectively. There are only four Provinces that run a petroleum surplus and they are Tianjin, Heilongjiang, Shaanxi and Xinjiang. Liaoning runs the largest petroleum deficit (43 mmt) followed by Zhejiang, Jiangsu, Shanghai and Ningxia, each of which have a deficit of around 20 mmt.

8.2. Electricity supply and demand

Although capacity building in the electricity production sector increased rapidly in China, it remains the case that it still cannot meet the rising demand for electricity. China's total installed capacity of electricity supply reached 700 million kW in 2007, of which coal power plants accounted for nearly 80% and hydropower stations accounted for nearly 20%. However, electricity supply is still far behind demand. For example, the excess demand for electricity comes from Beijing and Tianjin who had a 1.1 million kW shortage of electricity in 2007 [40]. China is hastening cooperation with Russia to transmit 10 million kW of electricity to the Northeast Grid from the Far East Grid, and negotiating with Inner Mongolia to transmit 12 million kW to the North China Grid from the Sino-Inner Mongolia coal powered plants [40]. Other forms of foreign-based electricity cooperation deals are also under negotiation.

8.3. Energy trade pattern

In general, China's energy imports are quite limited. Until 1996 China was a net exporter in term of aggregate energy. Post-1996, China's aggregate energy imports increased but with no obvious trend (Table 11). Only in recent years has a discernable, stable increase in net energy imports emerged rising from 53 million

Table 11
Export and imports and trade reliance of China's energy, million metric tonnes and %.

Year	Aggregate trade and reliance				Coal trade and reliance				Petroleum trade and reliance			
	Import	Export	Balance	Reliance	Import	Export	Balance	Reliance	Import	Export	Balance	Reliance
1980	2.6	30.6	−28.0	−4.6	2.0	6.3	−4.3	−0.7	0.8	18.1	−17.2	−19.7
1985	3.4	57.7	−54.3	−7.1	2.3	7.8	−5.5	−0.7	0.9	36.3	−35.4	−38.6
1990	13.1	58.8	−45.7	−4.6	2.0	17.3	−15.3	−1.4	7.6	31.1	−23.5	−20.5
1995	54.6	67.8	−13.2	−1.0	1.6	28.6	−27.0	−2.0	36.7	24.5	12.2	7.6
1996	68.4	75.3	−6.9	−0.5	3.2	36.5	−33.3	−2.3	45.4	27.0	18.4	10.6
1997	99.6	76.6	23.0	1.7	2.0	30.7	−28.7	−2.1	67.9	28.2	39.7	20.2
2000	143.3	90.3	53.1	3.8	2.2	55.1	−52.9	−4.0	97.5	21.7	75.8	33.8
2004	265.9	116.5	149.5	7.4	18.6	86.7	−68.1	−3.5	172.9	22.4	150.5	47.5
2005	269.5	114.5	155.1	6.9	26.2	71.7	−45.6	−2.1	171.6	28.9	142.8	43.9
2006	310.6	109.3	201.3	8.2	38.3	63.3	−25.0	−1.0	194.5	26.3	168.3	48.2
Growth rate annually:												
1980–1990	17.6	6.7	–	–	0.0	10.6	–	–	25.2	5.6	–	–
1990–2000	27.0	4.4	–	–	1.0	12.3	–	–	29.1	−3.5	–	–
2000–2006	13.8	3.2	24.9	13.7	61.0	2.3	−11.7	−20.6	12.2	3.3	14.2	6.1
1997–2006	15.6	4.4	27.3	19.3	38.7	8.4	−1.5	−7.7	14.6	0.1	17.4	10.2

Note: Aggregate energy is measured in million tonne standard coal and reliance is the percentage of net import in total domestic consumption.
Data source: China Statistical Yearbooks [17].

tonnes standard coal equivalence in 2000 to over 200 million tonnes standard coal equivalence in 2006. This means China's energy import dependence has increased from 3.8% in 2000 to 8.2% in 2006. This pattern of energy trade is determined by two major characteristics of China's energy supply and demand; abundance of coal deposits and rising demand for petroleum.

China remains a net exporter of coal, but the surplus is declining. To meet the domestic demand for special types of coal, China imports some coal and since 2000 this has been increasing in volume of coal import to reach nearly 40 million tonnes standard coal equivalence in 2006. On the other hand, the volume of coal exports is still small and has not shown an apparent rising trend. As a result, China's net exports of coal have been limited accounting for a small percentage of total domestic coal consumption.

When we turn to petroleum, however, the picture is reversed. China's petroleum imports have increased rapidly; from 37 mmt in 1995 to 98 mmt in 2000 and 195 mmt in 2006. Exports have been stable at approximate 25 mmt since 1995. The share of imports of petroleum was only 7.6% in 1995, but increased to 33.8% in 2000, and is now almost 50% since then.

There is little reason to believe that the pattern of energy trade will change in the foreseeable future given the current energy market situation. The rapid growth of the residential sector and demand for private vehicles is likely to exacerbate China's reliance on imported petroleum products. China also faces some other challenges. Firstly, coal is not a good substitute for oil despite the abundance of coal deposits. Secondly, transportation more generally is one of the largest consumers of petroleum products in the world. Thirdly, rising domestic petroleum consumption appears unavoidable. Finally, this situation will become more severe if no new oil fields are discovered and current oil fields are unable to maintain current output.

9. Renewable energy laws, programs and policy

9.1. Unfavorable energy situation

As can be seen from above, China is facing two severe challenges of energy shortage and environment protection. Both challenges are mainly rooted in the characteristics of China's energy supply. China's petroleum consumption has been sharply increasing, particularly since the new millennium. It is even worse that the ratio of petroleum reserves to production was only 11.3 years as of the end of 2007 [15]. Since coal is its major source of primary energy, China is facing severe environmental pollution. Therefore, in order to maintain fast and stable economic China has to find a sustainable policy for energy development and consumption.

9.2. Renewable energy laws

Energy laws and regulation have also assumed a higher profile in China, against a historic background where energy-saving was not given much attention. For example, the Energy-Saving Law was drafted in 1997, issued in 1998, revised in 2007 and reissued in 2008.

China's laws for renewable and sustainable energy development and consumption came very late. For example, Renewable Energy Law of the People's Republic of China was adopted at the 14th Meeting of the Standing Committee of the Tenth National People's Congress on February 28, 2005 and went into effect as of January 1, 2006. This Law is to promote the exploitation of renewable energy, increase energy supply, improve the energy structure, ensure energy safety, protect the environment, and attain the sustainable development of the economy and society. In fact, 1 year after the Renewable Energy Law went into effect, China's total renewable energy use reached 180 million tonnes coal equivalent in 2006, accounting for 7.5% of total primary energy consumption [41]. Comparatively, renewable energy use was only 63.33 million tonnes coal equivalent and accounted for only 2.5% of total energy consumption in 2005 [18]. As a result, renewable energy use reduced 3 million tonnes of SO_2 emissions and saved 1000 million cube meter of water in 2006 [41].[5]

As China's economy has developed rapidly over the past several decades, the country has struggled to figure out how to maintain a healthy environment. Therefore, the fourth session of the Standing Committee of the 11th National People's Congress adopted Economy Promotion Law of the People's Republic of China on August 29, 2008, with effect from January 1, 2009. This economic law is closely correlated to Renewable Energy Law, with purposes to facilitate recycling economy, raise resources utilization efficiency, protect and improve the environment and realize sustainable development.

9.3. Renewable energy research and programs

While China's renewable energy law was only recently issued, academic research on renewable energy techniques and specific renewable energy projects commenced much earlier. For example, The Institute of Nuclear and New Energy Technology (INNET),[6] Tsinghua University, was established in 1960, with its renewable energy research emphasizing hydrogen energy and biofuel studies. Guangzhou Institute of Energy Conversion (GIEC), Chinese Academy of Sciences (CAS), was founded in 1978, and recently emphasizes new and renewable energy utilization technology and energy regeneration technology for environmental pollution abatement.[7] The Center for Renewable Energy Development (CRED), Energy Research Institute of State Development and Reform Commission (NDRC), was established in the 1980s, to focus on economic and development policy of renewable energy.[8] The biogas Institute of the Ministry of Agriculture (BIOMA) was established in 1979 directly associated under the Chinese Academy of Agricultural Sciences (CAAS), with integration of biogas fermentation research, technical development, engineering project design and technical training. Recently, many such institutes have been established, for example, Institute of Energy,[9] Shanghai Jiaotong University, and the School of Energy Research,[10] Xiamen University. In fact, almost each province has its own energy institute.

China carried out renewable energy programs as early as in the 1970s, while most of large scale programs were launched in the 1990s. For example, State Planning Commission (changed to State Development and Planning Commission in 1998 and to State Development and Reform Commission in 2003) launched a Bright Project Provide renewable power to 20 million Chinese citizens in 1996, Crop Stalk Gasification Project for the general rural area to promote and extend the crop stalk gasification techniques in 1998, Acceleration Plan for Bright Project to provide a capital of ¥1800 million (approximate US$ 257 million) for solar energy and wind energy projects in 2002, and Rural Household Marsh Gas State Debt Project to construct the marsh gas construction with state debt capital in 2002 [18]. In addition, other government and international agencies also carry out renewable energy program in China.

[5] Deming Chen was former deputy director of State Development and Reform Commission at that time. Currently he is the Minister of Commerce of People's Republic of China.
[6] For detail refer to: http://www.inet.tsinghua.edu.cn/english2/news.php.
[7] For detail refer to: http://www.giec.ac.cn/giec2008_english/index.html.
[8] For detail refer to: http://www.cred.org.cn/en/main.asp.
[9] For detail refer to: http://energy.sjtu.edu.cn/.
[10] For detail refer to: http://energy.xmu.edu.cn/.

9.4. Renewable energy development policies

However, China's renewable energy is still unable to compete with fossil energy, and its development is dependent upon the government support. In fact, Chinese government has issued many priority policies to encourage and develop renewable energy since the late 1970s. Specifically, they are, for example, economic encouragement policy (e.g., financial subsidy, favorable taxation policy, and favorable price policy), industrialized support policy, technical research and development policy, and government renewable resources model projects.[11] However, Chen [41] noted that much is to be done support policies for renewable energy development in China. As Zhang et al. [18] conclude, for example, there is lack of coordination and consistence in policy, weak and incomplete encouragement system, no innovation in regional policy, incomplete financing system for renewable energy projects, and inadequate investment in the technical research and development for renewable energy, etc.

10. Looking ahead: challenges and opportunities

The factors that affect China's energy demand and supply have been well documented [42,43]. However, what are the factors that drive energy demand and supply? We attempt to identify them below.

10.1. Factors affecting energy demand

10.1.1. Rapid income growth

As per capita income grows, consumers will need more energy and potentially cleaner energy. At present per capita energy consumption in China is relatively low for example, electricity consumption per capita in Mainland China was 249 kWh in 2006. This is to be contrasted with (in 2005) 8365 kWh for the OECD (All); 11056 kWh in North America; 8482 kWh in OECD (Pacific); 6415 kWh in OECD (European); and 2596 kWh (World average) [13]. China's consumption of electricity per capita is therefore only 25% of the world average. As this consumption raises the demands on China's production sector will become enormous.

10.1.2. Growing urbanization

There remains a substantial rural–urban gap in energy consumption per capita in China for example, per capita electricity consumption per capita in urban areas was approximate 370 kWh in 2006, while it was only 190 kWh in rural areas. In addition, the urban population proportion rose rapidly from 30% in 1996 to 44% in 2006 [17].

10.1.3. Expanding transportation

This includes public and private transportation developments. The rapid expansion of the transportation sector has inevitably led to an increase in the demand for energy, especially oil products [42]. The total annual growth rate of total civil vehicle was 12.2% between 1995 and 2006. The growth rate for private vehicle was even faster, whose annual growth rate was 18.2% from 1995 to 2006, making total private vehicle from 4.18 million in 1995 to 26.20 million in 2006 [17].

10.1.4. Lagging energy pricing reform

The impact of energy prices on energy intensity has been extensively discussed in Hang and Tu [34]. Ma et al. [38] estimate the elasticity of demand for energy. Fan et al. [44] report measures of the own-price elasticity at -1.236 for the period 1993–2005. The impacts of raising energy prices on energy demand are evident.

[11] For other laws, regulations and general policies see Zhang et al. [18].

10.1.5. Increasing energy-intensive exports

China's energy-intensive exports have significantly increased domestic energy consumption. Kahrl and Roland-Holst [45] estimate that net exports accounted for 15–22% of China's total energy consumption which, since 2002, has significantly contributed to the increase in China's measured energy intensity. This suggests that the energy intensity of exports is higher than that of non-exports. The energy intensity of exports rose 8% annually, almost the same rate as national economic growth. Moreover, rising energy-intensive exports exaggerates greenhouse gas emissions and in turn China has been to be blame for having already become the second largest emitter of greenhouse gas. In fact, though within 5 years China's CO_2 emissions have nearly doubled, Weber et al. [46] find that in 2005 around one-third of Chinese emissions (1700 Mt CO_2) were due to production of exports. It is evident that consumption in the developed world is driving China's greenhouse gas emission.

10.2. Factors affecting energy supply

10.2.1. Increasing investment

Total investment in the energy industry was ¥521 billion in 1995 (in 2006 price) and ¥1751.3 billion in 2006, the growth rate of 11.6% per annum over the last decade. However, this growth rate could not keep in pace with the whole national investment growth. The share of investment of energy industry in the whole national investment was 21.4% in 1995, however, this share decreased to 14.7% in 2006, a one percent per annum drop since 1995.

10.2.2. Enhancing innovation

Here we will consider issues related to new energy sources and energy supply initiatives. The National Plan for medium- and Long-Term Scientific and Technological Development (2006–2010) in written in 2005 raised issues relating to innovation in the sector. Dorian and Clark [4] assessed China's potential for primary energy distribution based on the similarity of geographical structure between China and U.S. They suggest, for example, that China's Gansu, Qinghai Anhui, Sichuan and Chongqing areas are likely to be oil rich [4]. However, nothing has eventuated and the statistics do not show crude oil production in these Provinces (Tables 3–9).

10.2.3. Exploring renewable energy

There are various types of renewable energies, of them hydropower and nuclear energies are two of most important. As discussed previously, exploitable hydropower is approximate 400 million kW. To date 116 million kW has been developed. Nuclear energy has developed very slowly in China. It accounted for only 2.1% of total electricity supply in 2005 while world average for the same period was 15.2% [13]. The share of nuclear electricity in total electricity generation in many countries is often as large as 40% for example, France 80%, Ukraine 48%; Sweden 46%; Belgium 55%; Switzerland and Bulgaria 41% [13]. In addition, biomass energy even plays a more important role in rural household energy demand. For the potential of rural biomass resources and consumption, in particular crop residue, see Liu et al. [11].

10.2.4. Improving energy efficiency

Energy efficiency is actually a two-edged sword. Its improvement can directly reduce energy consumption and at the same it can alleviate pressure on energy supply. With a series of adjustment of industrial structure and the introduction of many energy efficiency programs, China's energy intensity has been declining during the last two decades. However, China's energy efficiency is still fairly low relative to other developed countries and regions. As a result, energy intensity is still high in the world (see previous section). It is clear that China's energy supply would

have increased by 30% had China's energy intensity been only twice as high as the world average. The potential of improving energy efficiency is huge in China. Improving energy efficiency is even more important than exploring existing energy resource in this millennium.

10.2.5. Quickening energy reforms

Energy reforms in the energy sector came many forms, which have involved both supply and demand. China's energy economy has been fundamentally reshaped following the introduction and implementation of a number of reforms (referring to in previous sections). However, a completely competitive energy market has not yet been achieved. For example, competitive wholesale markets and retail access are still in the experimental phase. Once fully implemented this may produce a significant effect on energy efficiency. In addition, China's electricity prices are still low relative to world averages which may reduce demand side efficiencies. Hang and Tu [34] have modeled the effects of price changes on energy intensity and conclude, not surprisingly, that higher energy prices lead to a decrease in energy intensity. Increasing energy prices will improve energy efficiency and therefore increase energy supply relatively.

10.2.6. Alleviating traffic congestion

China's traffic can be one of the most congested in the world. The traffic regulation may be also the worst in the world. Improving traffic administration may be another way to saving energy and improving the energy efficiency of the transport sector. According to research, only 15% of the energy from the fuel is used to move the car. Driving in urban areas, 17.2% of fuel is lost due to idling stop lights or traffic congestion [47]. Therefore, the potential to improve driving fuel efficiency is enormous.

11. Policy directions

It should be clear that even the most desirable combination of factors discussed above will not prevent a significant increase in China's primary energy consumption and electricity generation [7]. China's energy policy makers are really in the dilemma [48]. Choices are inevitable. Chinese policymakers must decide for themselves how and what to prioritize. To mitigate China's energy demand pressure and ease the coal-use-environment dilemma, in fact, many studies have provided China's government many valuable policy options. For example, Sinton et al. [49] present a comprehensive valuation of China's energy straggly options. Combing the contributions made from previous studies, this study proposes the following policy directions for the Chinese government to consider in the near future:

- Maintaining and increasing investment in the energy industry.
- Enhancing technical innovation. Technical innovations come many forms, which are involved in both energy supply and demand sides. This also includes introducing overseas advanced energy techniques.
- Coordinating environment and resource policy. China's energy industry is confronted with dual pressures from economic development and environmental protection [50]. Biomass and coal are two of the larges pollutants in China. For example, coal combustion produces 70% of China's carbon dioxide, 90% of sulfur dioxide emissions and 67% of nitrogen oxide emissions [49]. Therefore, improving biomass and coal's combustion efficiency is one of the most direct ways to reducing environmental pollution.
- Coordinating with energy exploitation and conservation. To meet rising energy demand does not necessarily mean to have to increase energy supply, while to save energy use is also a smarter way to meeting rising energy demand. Therefore, in the long-run, China's government has to make great effort not only to increase energy supply but to save energy use as well. Prioritizing investment in energy efficiency rather than pouring money into expanding energy supply should be strongly recommended. Wang et al. [51] put forward 13 main barriers to energy saving in China after reviewing literatures on energy saving and opinion of experts from energy industry and academia. These main barriers on energy saving are worthy of being paid attention from China's policymakers.
- Strengthening institutions. Raising the price of energy to reflect national priorities will require strengthened institutions with the capacity to make these kinds of changes. One possible solution is to establish an independent "Ministry of Energy," which would formalize the government's commitment to energy issues and improve enforcement of energy regulations and could integrate energy industry both over regional level and over energy sources, which means that energy policies are not independent implemented within each of energy sources but considered as a whole energy industry (all of energy sources).
- Employing Kyoto Protocol for self-defense. During the past two decades, China's exports are mainly energy-intensive based. China's increasing exports actually has been at the expense of depletion of domestic energy resources though exports are one of the most important drivers of fast economic growth in China. It may be impossible for China's government to choose between economic growth and resource conservation at this stage. However, China should request Kyoto parties to count the incremental cost of environment protection within the framework of the Clean Development Mechanism and would allow some of the importers of China's carbon-intensive goods to invest in lowering the carbon intensity of Chinese exports. The reason appears simple because importers of China's commodities benefit a lot. For example, Li and Hewitt [52] find that through trade with China the UK reduced its CO_2 emissions by approximately 11% in 2004. Shui and Harriss [53] estimate that that US CO_2 emissions would have increased from 3% to 6% if the goods imported from China had been manufactured in the US while 7–14% of China's current CO_2 emissions were a result of producing exports for US consumers during 1997–2003.
- Increasing investment in renewable energies. Renewable energies only account for less than 10% of the world's total energy consumption but nearly 20% of China's total primary energy consumption [50]. The potential of renewable energies is enormous due to its unlimited supply and its cleanliness in use. Moreover, once the Kyoto Protocol is fully implemented by all the signatories, the incentive of using renewable energies will be greatly increased. The opportunities and challenges for renewable energy policies can refer to Zhang et al. [18].
- Improving traffic administration techniques and reforming traffic regulation.
- Increasing international energy cooperation and joint ventures.

12. Conclusion

The above discussion brings about a comprehensive overview of China's energy situation in the new millennium. As can be seen, China's energy situation is quite dynamic, in some degree, which is apparently dependent upon the energy policy. Continuing fast economic growth inevitably drives energy demand increase. With the feature of coal as major primary energy resource, there are a series of challenges Chinese government have to meet. With increasing demand for clean energy, large quantity of funds is needed in the generation of electricity and environment protection facilities. Increasing exports also significantly drive the rapid increase in domestic energy demand, and in return drive greenhouse gas emissions.

China's industrialization, modernization and urbanization have affected the way in which energy resources have been and will be used to facilitate economic growth [3]. China's future in political, economic and human terms is of enormous importance to the world. The decisions that China makes in relation to its energy policy will present both challenges and opportunities for the world.

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